Upper Cervical Spine Injuries

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Abstract

The unique anatomy of the upper cervical spine and the typical mechanisms of injury yield a predictable variety of injury patterns. Traumatic ligamentous injuries of the atlanto-occipital joint and transverse atlantal ligament are relatively uncommon, have a poor prognosis for healing, and often respond best to surgical stabilization. Bony injuries, including occipital condyle fractures, atlas fractures, most odontoid fractures, and traumatic spondylolisthesis of the axis, generally respond well to nonsurgical management. Controversy in management remains, however, especially with type II odontoid fractures.

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The upper cervical spine, or cervicocranium, includes the articulations of the occiput with the atlas and the atlas with the axis, as well as the bony structures of the base of the skull, axis, and atlas. Injuries to this region are relatively common and generally occur as a result of significant forces applied to the head during trauma. Morbidity and mortality appear to be declining as a result of enhanced automobile safety measures and more attentive emergent care.[1] However, these injuries can be easily overlooked. The complex regional anatomy and overlying structures make plain radiographic images difficult to interpret. Delayed recognition or improper treatment can result in significant disability. The goals of treatment are to protect the neural structures, reduce and stabilize the injured segment, and provide long-term stability. A thorough understanding of the clinical presentation, radiographic assessment, and mechanisms of injury can minimize morbidity and enhance treatment effectiveness for the more common upper cervical ligamentous and bony injuries.

Anatomy

Unlike the subaxial spine, each level of the upper cervical spine is anatomically unique, with complex stabilizing structures (Fig. 1). The highly specialized anatomy allows weight transfer between the head and trunk; facilitates neck motion; and protects the spinal cord, brain stem, and vertebral arteries. The occiput articulates with the atlas through paired synovial joints. The paired occipital condyles project inferiorly from the occiput at the anterolateral margin of the foramen magnum. The concave atlantal lateral masses accept the occipital condyles to form the articulation. These joints are shallower and less well developed in children, thus contributing to the higher incidence of atlanto-occipital injuries in the pediatric population. The lateral masses are connected by an anterior and a posterior arch. The anterior tubercle, located in the midline on the anterior arch, serves as the attachment site for the anterior longitudinal ligament and longus colli muscles. The posterior tubercle serves as the attachment site for the ligamentum nuchae. A groove on the superior surface of the posterior arch accepts the vertebral artery after it passes through the foramen transversarium.

The odontoid process, or dens, extends rostrally from the body of the axis to articulate with the posterior aspect of the anterior arch of the atlas. This joint is synovial, as are the laterally placed paired facet joints through which the atlas and axis articulate. The superior facets of the axis are concave; together with the odontoid articulation, this facilitates rotation. The spinous process of the axis is generally large and bifid.

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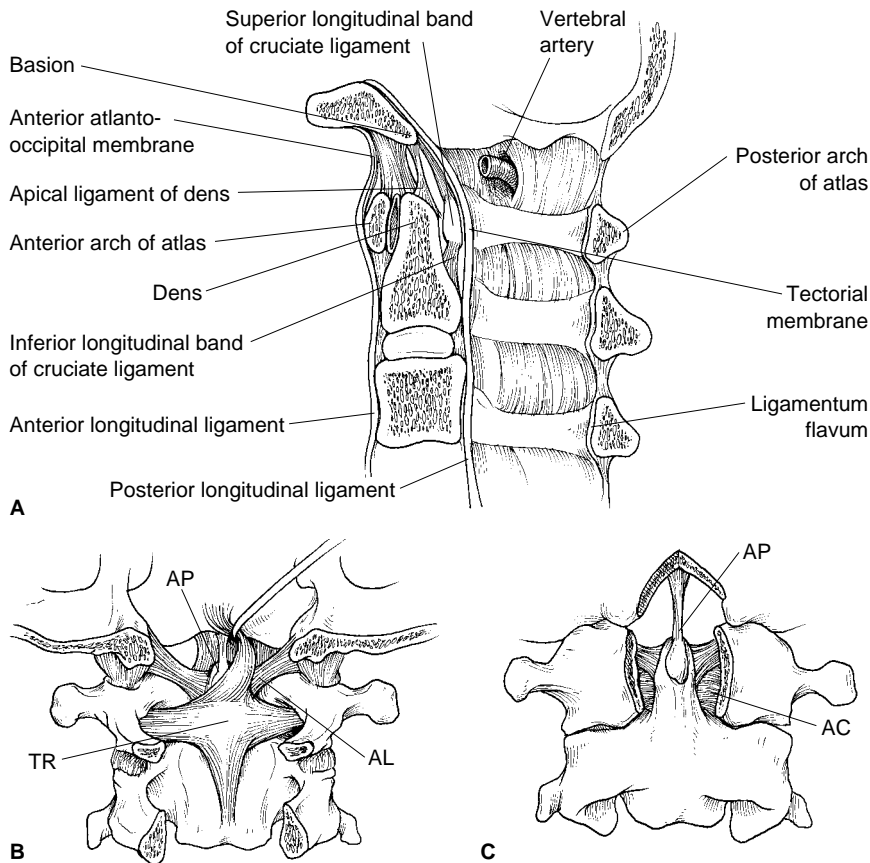
Figure 1 **A,** Sagittal view of the occipitocervical articulation. Posterior **(B)** and anterior **(C)** views of the atlantoaxial articulation. AP = apical ligament; TR = transverse atlantal ligament; AL = alar ligament; AC = accessory ligament. (Adapted with permission from Heller J, Pedlow F: Anatomy of the cervical spine, in Clark CR, Dvorak J, Ducker TB, et al [eds]: *The Cervical Spine*, ed 3. Philadelphia, PA: Lippincott-Raven, 1998, pp 8-9.)

and body of the axis. The odontoid ligaments (alar and apical ligaments) are the most ventral ligamentous structures. The paired alar ligaments connect the odontoid to the occipital condyles. They measure 5 to 6 mm in diameter and are relatively strong, in contrast with the small apical ligament that runs vertically between the odontoid and foramen magnum.

The range of motion between the occiput and atlas is 25° in flexion-extension, 5° to each side in lateral bending, and 5° to each side in rotation.[2,3] The range of motion between the atlas and axis is 20° in flexion-extension, 5° in lateral bending, and 40° in rotation. The major stabilizing structures between the occiput and upper cervical spine are the tectorial membrane and alar ligaments. Flexion is limited by the bony anatomy, while extension is limited by the tectorial membrane. Rotation and lateral bending are restricted by the contralateral alar ligaments. Distraction >2 mm is prevented by the tectorial membrane and alar ligaments. Translation should not exceed 1 mm and is limited by the facet joints, when there are an intact tectorial membrane and alar ligaments.

Evaluation

Upper cervical spine injuries can result from various traumatic events. Motor vehicle accidents are the most frequent cause; however, falls, diving accidents, and gunshot wounds are also common mechanisms. In addition, individuals may be predisposed to injury by congenital or developmental abnormalities, arthritic conditions, or tumors.

Patients with an upper cervical injury may have an associated head injury, which can alter their level of consciousness and complicate obtaining an accurate history and physical examination. Consequently, all

The craniocervical ligamentous anatomy can be subdivided into intrinsic and extrinsic ligaments. The extrinsic ligaments include the ligamentum nuchae, which extends from the external occipital protuberance to the posterior aspect of the atlas and cervical spinous processes. Fibroelastic membranes replace the anterior longitudinal ligament, intervertebral disks, and ligamentum flavum between the occiput and atlas and between the atlas and axis. The atlanto-occipital and atlanto-axial joint capsules also contribute to the extrinsic stability.

The intrinsic ligaments, located within the spinal canal, provide most of the ligamentous stability.

These ligaments form three layers anterior to the dura. From dorsal to ventral, they include the tectorial membrane, the cruciate ligament, and the odontoid ligaments. The tectorial membrane connects the posterior body of the axis to the anterior foramen magnum and is the cephalad continuation of the posterior longitudinal ligament. The cruciate ligament lies anterior to the tectorial membrane, behind the odontoid process. The transverse atlantal ligament is the strongest component, connecting the posterior odontoid to the anterior atlas arch, inserting laterally on bony tubercles. Vertical bands extend from the transverse ligament to the foramen magnum

patients who sustain significant polytrauma and/or head trauma should be assumed to have a cervical spine injury and undergo appropriate screening radiographic studies.

The history should be obtained from the patient if possible or, alternatively, from a witness. Important aspects of the history are mechanism of injury (including potential forces imparted by the injury), whether the patient was restrained, and whether transient motor or sensory deficits occurred at the scene of the accident. Awake patients will often complain of neck pain or headache. Advanced Trauma Life Support procedures to maintain the airway, breathing, and resuscitation should be the first priority. A careful, complete physical examination of the entire spine should follow—inspection, palpation, and neurologic evaluation while the head and neck are stabilized in neutral alignment. Neurologic examination should include testing of the cranial nerves as well as motor function, sensory perception, and reflexes in the extremities. Results of neurologic examination may range from normal sensorimotor functions to variable sensorimotor impairment, including incomplete to complete spinal cord injury. Cranial nerve injury—including of nerves VI, VII, IX, XI, and XII—may result from upper cervical injuries and should not be overlooked.[4,5]

Considerable controversy surrounds the proper composition of a screening radiographic cervical spine assessment. Some think this should routinely include anteroposterior (AP), lateral, and open-mouth views.[6] Others feel that a lateral view is sufficient in a patient without suspected injury, yet the examination should include an open-mouth view whenever upper cervical spine injury is suspected. The lateral radiograph should visualize the entire cervical spine from the base of the skull to T1. For specific injuries,

computed tomography (CT) and magnetic resonance imaging (MRI) may yield additional diagnostic information.

With a normal atlanto-occipital relationship, the clivus on lateral radiograph should point toward the tip of the odontoid, and the basion (tip of the clivus) should be within 5 mm of the odontoid vertically. Retropharyngeal soft-tissue swelling >5 mm at C3 is abnormal and should raise suspicion for the presence of an anterior arch fracture of the atlas. A diastasis >2 mm between the occiput and atlas is also abnormal. Harris et al[7] described the rule of 12, which is superior to the Powers ratio for identifying occipitocervical dissociation. The rule of 12 uses three landmarks: the basion, the rostral tip of the odontoid, and the rostral extension of the posterior cortical margin of the axis (posterior axial line). The basion-axial interval is the distance between the basion and the posterior axial line; the basion-dental interval is the distance between the basion and the tip of the odontoid. The method is applicable to adults and to children older than 13 years. Both intervals should be <12 mm in normal individuals (Fig. 2).

An open-mouth radiograph allows visualization of the atlas, odontoid process, and lateral masses of the axis. Although the lateral masses of the atlas normally articulate symmetrically with the axis, asymmetry between the dens and the lateral masses of the atlas is not always indicative of injury.

Supervised flexion and extension lateral radiographs may be helpful in recognizing instability at both occiput-C1 and C1-C2 and in differentiating type I traumatic spondylolisthesis of the axis from type II. There is an inherent danger to a patient with instability when obtaining flexion and extension radiographs.[8] Careful follow-up is necessary in patients with initial cervical muscle
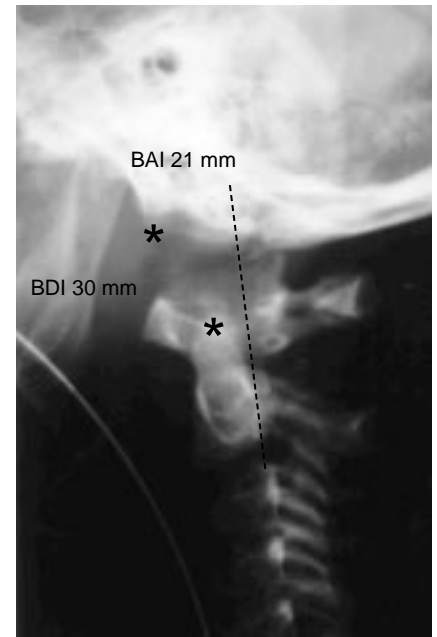
Figure 2 Occipitocervical dissociation demonstrating the rule of 12. The upper asterisk identifies the basion and the lower asterisk, the axial dens. The distance between them is the basion-dental interval (BDI). The dashed line represents the posterior axial line. The distance between it and the basion (upper asterisk) is the basion-axial interval (BAI). Both distances are >12 mm and clearly abnormal.

spasm because the spasm may mask instability in the acute setting.

CT is a very sensitive method for evaluating craniocervical relationships and is the preferred method for evaluating most suspected injuries in the upper cervical spine.[9] Properly oriented thin slices are necessary in the CT scan to allow visualization of fractures and to achieve adequate quality reconstruction. MRI is occasionally used to assess patients with neural deficit or with suspected ligamentous injury (especially the transverse atlantal ligament).[10]

Types of Injury

Occipitocervical Dissociation

Occipitocervical ligamentous injuries have a high mortality rate.

In autopsy studies, they represent 5% to 12% of identified cervical injuries; the most common mechanism is pedestrians struck by motor vehicles.[11,12] Prompt recognition, high index of suspicion, and immobilization are essential. Children are predisposed to these injuries because of their inherent ligamentous laxity, immature occipitocervical joints, and larger ratio of head to body size than in adults.

Occipital Condyle Fractures

Occipital condyle fractures, commonly caused by an axial compression mechanism, are frequently diagnosed as a concurrent finding on head CT scan done for trauma. The classification system described by Anderson and Montesano[9] was based on CT pattern and evaluates the potential for instability.

A type I injury (Fig. 3) is a comminuted (impaction) fracture of the condyle and is generally stable. A type II fracture is a condyle fracture with associated basilar skull fracture. This injury is stable except when the entire condyle is separated from the occiput. A type III injury is an avulsion fracture of the attachment of the alar ligaments. This injury can be bilateral and occurs in 30% to 50% of patients with atlantooccipital dislocations.[4]

Stable type I and II fractures should be treated in a collar for 6 to 8 weeks. Displaced type II injuries should be treated in a halo vest for 8 to 12 weeks. Type III injuries are treated based on stability; stable nondisplaced injuries are treated in a collar, and minimally displaced injuries are treated in a halo vest. Any evidence of AP displacement, joint incongruity, or abnormal diastasis makes the injury unstable, necessitating an occiput-C2 fusion.[4]

Occipitocervical Instability

This injury can occur as a result of several different mechanisms and can be classified according to the direction of occipital displacement[5] (Fig. 4). Type I injuries are most common and have anterior occipital displacement. Type II injuries have vertical displacement >2 mm between the occiput and C1. Vertical instability also can occur at C1-2 (type IIB) because the same ligamentous structures, the tectorial membrane and alar ligaments, resist distractive forces at both levels. Type III injuries are rare and have posterior occipital displacement.

Early diagnosis and treatment are critical because patients are at high risk for neurologic injury or sudden death. Once occipitocervical instability has been diagnosed, reduction of displacement can be performed cautiously with fluoroscopic guidance by carefully positioning the head with a bolster behind the thorax (for anterior displacement) or the occiput (for posterior displacement). Traction and collar immobilization can reproduce axial displacement, precipitating neurologic injury, and accordingly should be avoided. For vertical displacement, reduction can be performed by providing gentle downward pressure or by elevating the head of the bed.[4] A halo vest can provide temporary immobilization, but surgical stabilization is necessary. Occipitocervical fixation and arthrodesis, using plates with C2 fixation obtained with C1-2 transarticular screws or C2 pedicle screws,[4] is preferable to wire and graft techniques. Fixation with plates and screws obviates the need for a postoperative halo vest and more accurately maintains reduction.

Atlas Fractures

Fractures of the atlas constitute 10% of all cervical spine injuries.[13] There is a high prevalence (approaching 50%) of concomitant injuries, including odontoid fractures, hangman's fractures, and transverse atlantal ligament disruption.[14-16] Neurologic injury is rare because, when fractured, the ring of the atlas often expands, making more space available for the spinal cord.

Fracture classification is based on fracture morphology and associated ligamentous injury. Up to six injury

| Type I | Type II | Type III |
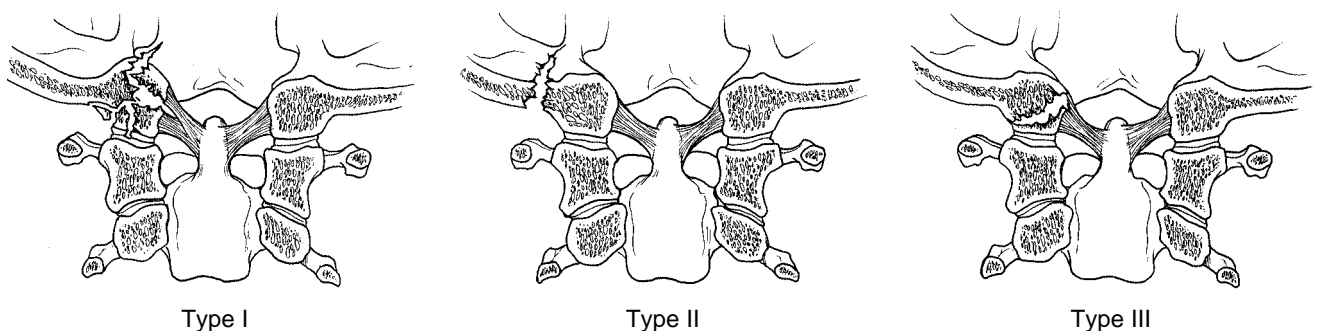
Figure 3 Classification of occipital condyle fractures. (Adapted with permission from Anderson PA: Injuries to the occipital cervical articulation, in Clark CR, Dvorak J, Ducker TB, et al [eds]: *The Cervical Spine*, ed 3. Philadelphia, PA: Lippincott-Raven, 1998, p 391.)
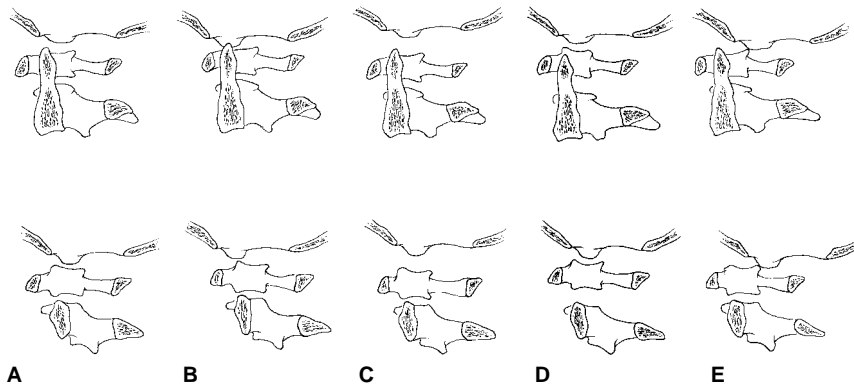
Figure 4 Classification of occipitocervical instability. **Top row,** Midsagittal representation. **Bottom row,** Parasagittal representation of the same injury. **A,** Normal. **B,** Type I, anterior displacement. **C,** Type IIA, vertical displacement between occiput and atlas. **D,** Type IIB, vertical displacement between atlas and axis. **E,** Type III, posterior displacement. (Adapted with permission from Anderson PA: Injuries to the occipital cervical articulation, in Clark CR, Dvorak J, Ducker TB, et al [eds]: *The Cervical Spine*, ed 3. Philadelphia, PA: Lippincott-Raven, 1998, p 393.)
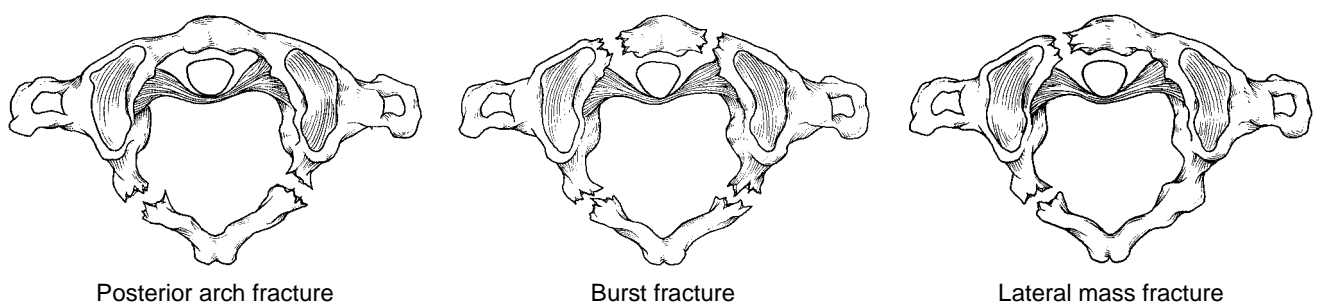
ing in intact secondary flexion restraints.

Avulsion injuries are treated symptomatically in a soft collar for 4 to 6 weeks. A posterior arch fracture, a stable injury, is treated in a collar for 10 to 12 weeks and has a high union rate. The anterior arch (blow-out) fracture may be accompanied by avulsion of the odontoid process by the apical and alar ligaments during extension and posterior translation of the head. Reduction of displacement may require slight flexion.[17] Anterior arch fractures have been treated successfully in halo vests, with the neck slightly flexed, or by C1-C2 posterior fusion in selected cases with instability.[17] Treatment of burst and lateral mass fractures is based on the amount of lateral mass displacement or instability, determined by open-mouth radiograph. Minimally displaced fractures (<7 mm total displacement) or significantly displaced fractures (≥7 mm) correspond to the integrity of the transverse ligament. Spence et al[18] demonstrated that combined displacement >6.9 mm occurs only with disruption of the transverse ligament (Fig. 6). Nondisplaced and minimally displaced fractures can be immobilized in a collar; displaced fractures require more definitive treatment.

types have been described, including posterior arch fractures, burst or Jefferson fractures, lateral mass fractures, anterior arch fractures (blow-out or plow fractures), anterior tubercle fractures, and transverse process fractures. Each individual type of atlas fracture generally results from a predictable mechanism of injury. The posterior arch fracture results from hyperextension; burst or Jefferson fractures, from symmetric axial load; and lateral mass fractures, from asymmetric axial loads. Posterior arch fractures are stable, as the lateral atlantal masses and anterior arch remain intact (Fig. 5, A). However, widely displaced burst and lateral mass fractures with a disrupted transverse atlantal ligament are unstable (Fig. 5, B and C). In burst fractures, rupture of the transverse ligament occurs as a result of tension secondary to displacement of the lateral masses of the atlas; however, the apical and alar ligaments are spared, in distinction to a transverse ligament rupture from a severe flexion injury. Additionally, the anterior and posterior C1-2 facet capsules are spared in the burst fracture, result-

Posterior arch fracture   Burst fracture   Lateral mass fracture

Figure 5 There are three common types of atlas fractures: posterior arch fractures, in which the lateral atlantal masses do not spread; burst or Jefferson fractures, in which the lateral masses will spread and displace laterally; and lateral mass fractures, in which lateral displacement of the lateral mass will occur only on the fracture side. (Adapted with permission from Heller J, Pedlow F: Anatomy of the cervical spine, in Clark CR, Dvorak J, Ducker TB, et al [eds]: *The Cervical Spine*, ed 3. Philadelphia, PA: Lippincott-Raven, 1998, p 410.)
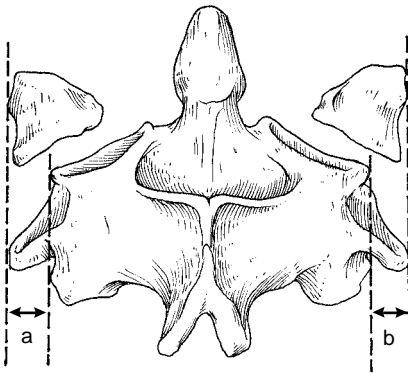
Figure 6 Assessing for transverse atlantal ligament injury on an open-mouth view of C1-2. The sum total of lateral displacement equals a + b. When the total displacement is >6.9 mm, rupture of the transverse ligament is assured. (Adapted with permission from Anderson PA: Injuries to the occipital cervical articulation, in Clark CR, Dvorak J, Ducker TB, et al [eds]: *The Cervical Spine*, ed 3. Philadelphia, PA: Lippincott-Raven, 1998, p 411.)

Nondisplaced or minimally displaced (≤5 mm) burst fractures can be treated in either a cervical orthosis or halo vest for 3 months and have a high union rate. A patient with a markedly displaced or unstable burst fracture is treated by anatomic reduction using traction, followed by either prolonged traction and halo immobilization or surgery. Reduction generally will not be maintained with immediate mobilization; therefore, traction of 4 to 6 weeks is required before mobilization in a halo vest if treated nonsurgically. Periodic open-mouth radiographs should be scrutinized for progressive lateral displacement of C1 lateral masses. Stabilization with C1-2 transarticular screws and fusion after reduction can be a primary treatment of unstable burst fractures,[19] allowing immediate mobilization. C1-C2 arthrodesis or occasionally occiput-C2 arthrodesis is indicated for progressive displacement after nonsurgical treatment, late C1-2 instability, or symptomatic C1 nonunion.

In a series of atlas fractures reported by Levine and Edwards,[15] results of treatment were generally good. Of 17 patients with posterior arch fractures, 9 had other associated cervical spine fractures. No patients had any symptoms related to the greater occipital nerve, and the only patient with a neurologic deficit had a concomitant odontoid process fracture. Of 15 surviving patients with lateral mass or burst fractures, 80% had residual neck pain but did not require surgical treatment. Only one nonunion developed. No late atlantoaxial instability was noted.

Rupture of the Transverse Ligament

Rupture of the transverse atlantal ligament is generally caused by a flexion force and often affects not only the transverse ligament but also the alar and apical ligaments. With an intact ligament, the maximal atlantodens interval (ADI) is 3 mm in an adult and 5 mm in a child. Experimentally produced transverse ligament insufficiency with intact alar and apical ligaments results in a maximal translation of 5 mm, as shown by Fielding et al.[20] Displacement >7 mm was associated with loss of integrity of the alar ligament and tectorial membrane. Complete ligamentous disruption can be accompanied by a significant incidence of neurologic injury. In addition, headache, nausea, visual abnormalities, and sensorimotor deficits may result from vertebral artery compression.

Disruption may occur in isolation or in association with other upper cervical injuries. Using thin-section CT or MRI, Dickman et al[21] classified disruptions of the midsubstance of the ligament as type I injuries, and avulsions of the ligament from the C1 lateral mass as type II injuries.

Treatment depends on the degree of initial displacement and identifi-cation of any coexistent fractures. If the ADI is ≤5 mm in a neurologically intact patient, collar immobilization is sufficient initially. For an ADI >5 mm, nonsurgical treatment including halo immobilization has generally yielded poor results except for selected cases when a bony avulsion can be documented on CT. In the study by Dickman et al,[21] none of the type I injuries healed spontaneously, and all required arthrodesis. Of type II injuries, 74% healed with immobilization.[21] The method used for C1-C2 arthrodesis in patients with this injury needs to be carefully selected; some wire techniques, even with halo immobilization, can result in postoperative displacement. C1-C2 transarticular screw fixation for arthrodesis may be indicated.

Atlantoaxial Rotatory Deformities

Traumatic atlantoaxial rotatory deformities differ dramatically from those that occur spontaneously in children or in patients with rheumatoid arthritis. The traumatic mechanism is a combination of rotation and forward flexion. The traumatic injury in adults is often associated with impaction or avulsion injuries to the C1-2 articulation. Atlantoaxial rotatory deformities are best evaluated with dynamic CT.[22]

Levine and Edwards[13] recommend manipulation for cases of acute, traumatic atlantoaxial rotatory deformity. Traction is applied through the halo ring in an awake patient, using topical anesthetic applied to the posterior pharynx. The reduction can generally be heard and can be verified by transoral palpation of the C1 ring. If stable, a halo is applied. If unstable, then a C1-C2 arthrodesis is performed. If closed manipulation is unsuccessful or the injury is not discovered until late, an open reduction may be considered. Arthrodesis in either a reduced or in situ position is recommended for

instability, neurologic involvement, or failure of conservative measures to achieve or maintain reduction.[13]

Odontoid Fractures

Odontoid fractures constitute 8% to 18% of all cervical fractures, with neurologic deficits occurring in 10% to 20% of cases.[23-28] They represent 75% of childhood cervical spine fractures as a result of the large ratio of head to body size.[28] High-velocity trauma, such as motor vehicle accidents, accounts for most of these injuries in young adults, while low-velocity injuries, such as falls, account for the majority of injuries in the elderly and children.

The classification system of Anderson and D'Alonzo[23] was based on anatomic level of the fracture, which has been shown to have a correlation to prognosis for fracture healing (Fig. 7). Type I fractures occur at the tip of the odontoid process, cephalad to the transverse atlantal ligament. They are the least common odontoid injury and generally are stable. They may also represent an avulsion of the alar ligaments, which can occur in atlanto-occipital distraction injuries.[29] Type II fractures occur at the junction of the base of the odontoid and body of the axis. They are the most common fracture type and are least likely to heal with nonsurgical treatment. Type III fractures extend into the body of the axis. They may be more stable than type II fractures and have a higher union rate with nonsurgical treatment.

In children, fractures of the odontoid generally occur through the synchondrosis, below the base of the odontoid. In adults, the type II fracture line is above the fused growth plate. The synchondrosis scar may be confused with a fracture.

Initially, all nondisplaced and type I injuries are managed by collar immobilization. Type II and III fractures that are minimally displaced (<5 mm and/or <10° of angulation)

can be managed initially by collar immobilization before definitive treatment. Significantly displaced type II and III fractures (≥5 mm and/or ≥10°) should be placed in traction to reduce the fracture before definitive treatment.

Type I fractures that are not part of a more serious injury are immobilized in a cervical orthosis for 6 to 8 weeks. A type I injury can represent an unstable occipitocervical dislocation with loss of alar ligament integrity.[29] This injury may require an occiput-C2 fusion.

As a result of associated instability, lower rate of union, occurrence of concurrent fractures, and higher incidence of spinal cord injury, treatment decisions for type II fractures are more complex. Although reported nonunion rates range from 10% to 77%, certain risk factors can be predictive of nonunion. These include initial fracture displacement >5 mm, posterior displacement, fracture comminution, inability to achieve or maintain a reduction, and possibly increased patient age (>50 years old).[24-27,30,31]

Patients with nondisplaced or minimally displaced fractures that are easily reduced can be treated with halo vest immobilization for 12 weeks. Frequent radiographic evaluation is required to ensure maintenance of fracture alignment. Most studies demonstrate union rates of 84% to 100%,[24-26,32,33] with fractures initially displaced <4 to 6 mm but anatomically reduced and treated with a halo vest.

For patients with high-risk fractures, treatment alternatives include collar immobilization, halo vest immobilization, anterior osteosynthesis, and posterior C1-C2 arthrodesis. Collar immobilization does not control atlantoaxial motion and therefore leads to a high rate of nonunion.[34] Halo immobilization can provide adequate stability with satisfactory results in selected patients but may not be well tolerated by the
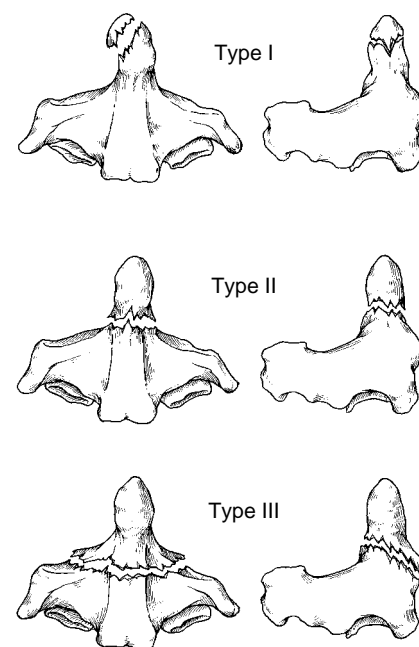
Figure 7 The three types of odontoid fractures viewed in the anteroposterior and lateral planes. Type I is an oblique fracture through the upper part of the odontoid process. Type II is a fracture at the junction of the odontoid process and axis. Type III is a fracture of the body of the axis. (Adapted with permission from Anderson LD, D'Alonzo RT: Fractures of the odontoid process of the axis. *J Bone Joint Surg Am* 1974;56:1663-1674.)

elderly.[34,35] In an elderly patient who also suffers increased surgical risk, the higher rate of nonunion from collar immobilization may be a reasonable alternative. Odontoid screw fixation has a high union rate and may preserve atlantoaxial motion. The potential problems include poor fixation in osteopenic patients and technical difficulty in patients with large chest size or posteriorly displaced fractures. Finally, posterior C1-C2 arthrodesis also has a high union rate, but fusion sacrifices atlantoaxial motion.[36] Both posterior arthrodesis and odontoid screw fixation have high rates of success—from 87% to 100% for posterior arthrodesis and 79% to 100% fracture union rates for screw fixation.[25,35-40]

| Type I | Type IA | Type II | Type IIA | Type III |
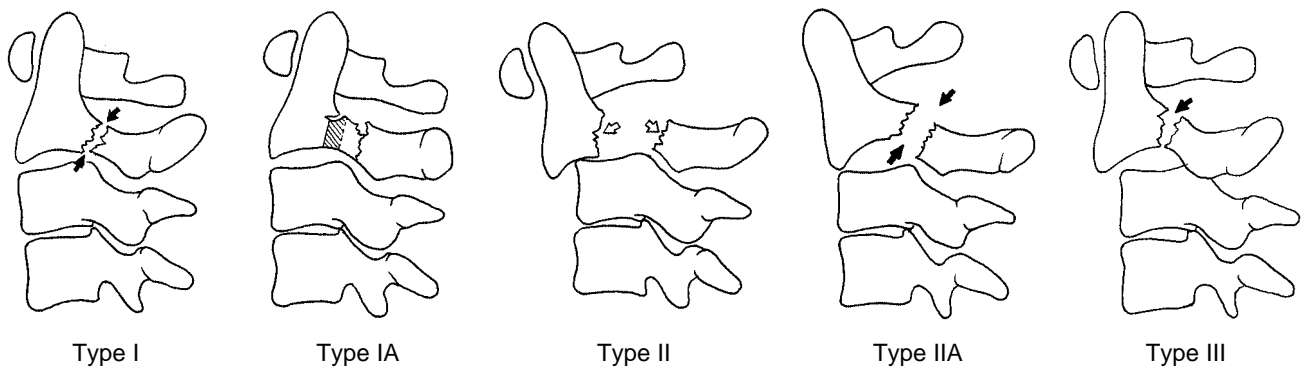
Figure 8 Classification of traumatic spondylolisthesis. Type I fracture through neural arch with no angulation and minimal displacement. Type IA fracture with elongation of the vertebral body and little angulation or translation. Type II fracture with significant angulation and displacement. Type IIA fracture with oblique fracture line and minimal translation but significant angulation. Type III fracture with bilateral facet dislocation. (Adapted with permission from Levine AM, Edwards CC: The management of traumatic spondylolisthesis of the axis. *J Bone Joint Surg Am* 1985;67:217-226.)

Type III fractures are best treated by halo vest immobilization; union rates exceed 95%.[23,25] Nonsurgical treatment has been shown to be more successful in skeletally immature individuals.[41] These fractures generally occur in children younger than 7 years of age and represent epiphyseal separations. Most fractures displace anteriorly and therefore require extension for satisfactory reduction. Nonunion is rare.

Fractures displaced <5 mm and/or <10° should be immobilized immediately in a halo vest. In children younger than 3 years of age, a Minerva jacket can be used. If displaced, reduction with traction and extension is instituted first, followed by halo vest immobilization for 8 to 12 weeks.

Traumatic Spondylolisthesis of the Axis

Traumatic spondylolisthesis of the axis most often occurs as a result of either motor vehicle accidents or falls and represents approximately 15% of all cervical spine fractures.[32] Although the fracture pattern may resemble that resulting from judicial hanging, the injuries are quite different. A properly accomplished judicial hanging results in a violent hyperextension injury to the spine with distraction, severing the spinal cord. Traumatic spondylolisthesis, however, results from hyperextension with axial load. Neurologic injury is uncommon because the fracture fragments separate, decompressing the spinal canal.

The hyperextension and axial load mechanism results in fractures of the pars interarticularis. With the more severe injury patterns, rebound flexion or flexion/distraction mechanism results in disruption of the C2-3 disk and posterior longitudinal ligament. Additionally, the anterior longitudinal ligament may be stripped from its bony attachment. The most severe and complex injuries most likely occur as a result of flexion, causing dislocation of the C2-3 facets, followed by hyperextension with axial load, producing the pars fractures secondarily.

The classification system for this injury was first described by Effendi et al[42] in 1981 and was later expanded by Levine and Edwards,[43] who described four fracture patterns. Others have added a fifth type[44] (Fig. 8). The classification is based on translation and angulation between C2 and C3. Type I injuries are bilateral pars fractures with translation <3 mm and no angulation. The C2-3 disk and ligamentous structures remain intact because the major injury is bony. Type IA is an atypical fracture and the most recently recognized.[44] There is minimal translation and little or no angulation. Elongation of the C2 body is often seen radiographically. CT will reveal extension of one fracture line into the body and often through the foramen transversarium. As a result, injury of the vertebral artery may occur.

In Type II fractures, the C2-3 disk and posterior longitudinal ligament are disrupted, resulting in translation >3 mm and marked angulation. The anterior longitudinal ligament generally remains intact but is stripped from its bony attachment. Type IIA fractures are less common. In contrast with type II, the fracture line is more oblique than vertical. There is little or no translation, but there is significant angulation. Traction will cause further fracture displacement and should be avoided.

Type III injuries are a combination of pars fracture with dislocation of the C2-3 facet joints. This injury is very unstable, with free-floating inferior articular processes. This is the most common injury to be asso-

ciated with neurologic deficit and requires surgery; it is irreducible by closed means.[43]

Type I and IA fractures can be treated by collar immobilization, both initially and definitively. Type II and IIA fractures require gentle reduction. Type II fractures require light traction and extension by placing a bolster behind the shoulders to achieve reduction. Type IIA fractures require extension and gentle axial load to achieve reduction. Type III fractures are irreducible closed because the dislocated inferior facets of C2 are not connected to any other bony structure as a result of the bipedicular fracture lying just anterior to them. Closed traction is therefore unable to provide reduction, and open reduction is required.

Once reduction is verified radiographically, type II fractures are immobilized in a halo vest for 6 to 8 weeks. Adjustment of the halo may be performed as necessary while monitoring fracture alignment. For type II fractures with displacement >5 mm and/or angulation >10°, traction is performed to reduce the displacement, followed by recumbency for 4 to 6 weeks, then halo immobilization for an additional 6 weeks. Alternatively, surgical stabilization with transpedicular lag screws may be considered if anatomic alignment can be achieved.[45] Because spontaneous anterior fusion is common, nonsurgical management is favored with type II injuries. Type III fractures require open reduction followed by internal fixation with a wiring or plating technique, based on the integrity of the facets and/or lamina.[45,46] Anterior C2-C3 plating also has been used.

Although no long-term studies exist, Levine and Edwards[43] reported on 52 patients with 4.5-year follow-up. Ninety percent of type I fractures healed; 10% had symptomatic degenerative changes. Seventy percent of type II fractures developed spontaneous anterior fusion. Type III fractures generally had a poor prognosis related to the resultant neurologic deficit. Francis et al[47] reported on 123 patients with traumatic spondylolisthesis of the axis, who had a 94.5% union rate regardless of initial displacement or angulation. Seventy-two percent were treated with traction and halo immobilization, with a 5% nonunion rate. Duration of traction did not influence fracture healing because 47% were treated with less than 2 weeks of traction, with only one nonunion. Alternatively, Verheggen and Jansen[48] favored surgical treatment with lag screws in 16 patients. All healed with preservation of atlantoaxial rotational mobility.

Summary

Injuries of the upper cervical spine are a major cause of morbidity and mortality. Although survival is increasing secondary to improved automobile safety measures and advances in emergent stabilization techniques, the injury patterns are numerous and the neurologic sequelae, diverse. Careful management, a high index of suspicion, and complete evaluation minimize delays in diagnosis. The possibility of concomitant injuries should always be suspected because the incidence is high. The goals of treatment are to protect the neural structures, reduce and stabilize the injured segment, and provide long-term stability. Nonsurgical treatment often can be instituted with a satisfactory outcome.

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